Effects of the intrinsic magnetic field on the ion loss from ancient Mars

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Mars had a thick atmosphere before 4 Ga, but it lost most of them. Ion escape to space could play an important role in the atmosphere loss. The astronomical observations suggest that the solar XUV (X-ray and extreme ultra-violet) flux and the solar mass loss rate were more intense (Ribas et al., 2005; Wood et al., 2002). Previous studies pointed out that the ion loss was several orders of magnitude stronger under such intensified solar conditions (Terada et al., 2009a). On the other hand, the existence of the crustal magnetic field indicates that Mars had an intrinsic magnetic field before 4.1 Ga. The conventional idea is that the intrinsic magnetic field prevents the direct interaction between the solar wind and the atmosphere and thus restrains the ion loss (Lundin et al., 2007). On the contrary, some studies suggested that the existence of an intrinsic magnetic field promotes the ion loss (Sakai et al., 2018). Thus it is important to clarify the effect of the intrinsic magnetic field on the ion loss to understand the atmospheric evolution at Mars.

In this study, we investigated the ion loss processes from Mars under extreme solar conditions and the existence of an intrinsic magnetic field using a 3D multi-species MHD model (Terada et al., 2009b). The solar wind proton density, the solar wind velocity, and the solar XUV flux were assumed to be 1000 /cm^3, 2000 km/s, and 100 times higher than the present-day XUV flux, respectively. The interplanetary magnetic field was assumed to be in Parker spiral and its strength was 60 nT. These parameters are same as those used in Terada et al. (2009a). We conducted four cases of simulations with different intrinsic magnetic field conditions, i.e., dipole fields with the strength of 0 nT, 100 nT, 1000 nT, and 5000 nT on the equatorial surface.

In 0 nT case, there were two major ion loss processes: escape of O^+, O_2^+ and CO_2^+ from the polar region and pickup O^+ carried by the deflected solar wind. In 1000 nT case, O_2^+ and CO_2^+ mainly came from the dayside cusp region through open magnetic field lines. In 5000 nT case, O^+, O_2^+ and CO_2^+ fluxes had almost the same structure and originated from the dayside cusp region. In 0 nT, 100 nT, and 1000 nT cases, the loss rates of O_2^+ and CO_2^+ were higher under the existence of the stronger dipole field, while the O^+ loss rate was nearly the same in these three cases. In 5000 nT case, the loss rates of O_2^+ and CO_2^+ were about three orders of magnitude lower than those of the other weaker dipole cases, while the O^+ loss rate was five times lower. These results suggest that the existence of a weak intrinsic magnetic field facilitates the loss of heavier ions such as O_2^+ and CO_2^+, and there is a threshold strength of the intrinsic magnetic field for this facilitation effect.

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